LECHAGO DAM. A CASE STUDY

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Paraules clau: dam, case history, finite element modelling, hydro-mechanical coupling

Resum: *Lechago dam (Teruel, Spain) is a 40 m high zoned earth and rockfill dam sitting on soft continental deltaic deposits. A relatively narrow central clay core is stabilized by wide rockfill shoulders. The dam was well instrumented and continuous records of stress, pore water pressures and displacements are available for the construction period. A coupled FE model has been developed to analyse the dam behaviour during construction. Model predictions, essentially based on laboratory tests, are compared with measurements during construction. The paper provides an integrated description of the dam design, construction and early behaviour.*

1. GENERAL DESCRIPTION OF THE LECHAGO DAM

Lechago dam is an earth and rockfill dam located in the northeast of Spain, in Teruel province. It was built in the period between April 2005 and January 2009. The dam was built on the valley of the Pancrudo river. Foundation soils are composed by a soft alluvial soil, in the lower central part of the valley, and ancient shales and quarzitic rocks, which form the steep lateral slopes of the valley. A cross-section of the valley is shown in Figure 1.

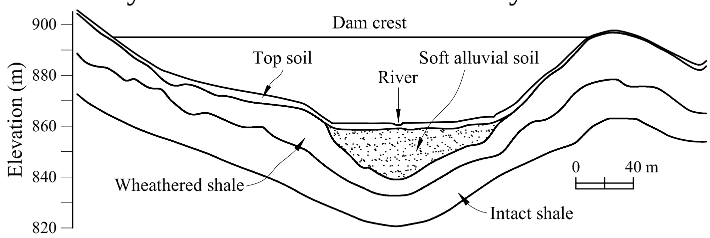

Figure 1: Central cross-section of Lechago dam.

Figure 2: Aerial photograph of Lechago dam at the end of its construction.

The non-symmetrical valley, the presence of soft continental deltaic sediments and the sharp transition between highly deformable and rigid strata were the main challenges to face during the design stage. As a result, Lechago dam has two definite cross-sections (Fig. 2). On the valley bottom the section is modified and two wide rockfill berms were added to improve the stability. With the aim of improving the undrained strength of the soft alluvial deposits, a preloading underneath the downstream shoulder and a dewatering were carried out. The dam was instrumented during construction.

3. MECHANICAL BEHAVIOUR OF COMPACTED SOILS AND FOUNDATION

The behaviour of the compacted materials of Lechago dam and foundation soils are described below. Some available laboratory tests have been simulated in the Code_Bright finite element program (Olivella, 1996) using the models mentioned above in order to calibrate the constitutive parameters of the materials and to use them in the model simulation of the dam construction.

3.1 Rockfill material

The rockfill material of Lechago shells was quarried around the dam site. Lechago rockfill has been extensely tested in the past decade in the Soil Mechanics Laboratory of UPC. The oedometric test by Oldecop and Alonso (2001) and the triaxial tests reported by (Chávez, 2004) (Figs. 3 and 4) have been chosen for the interpretation of the rockfill behaviour by means of the model published in Oldecop and Alonso (2001).

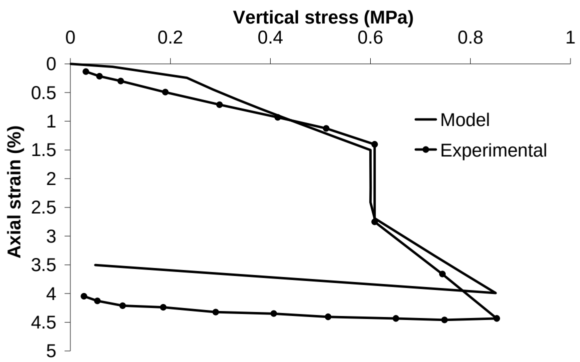

Figure 3: Oedometric test on Lechago Rockfill (experimental results by Oldecop and Alonso, 2001)

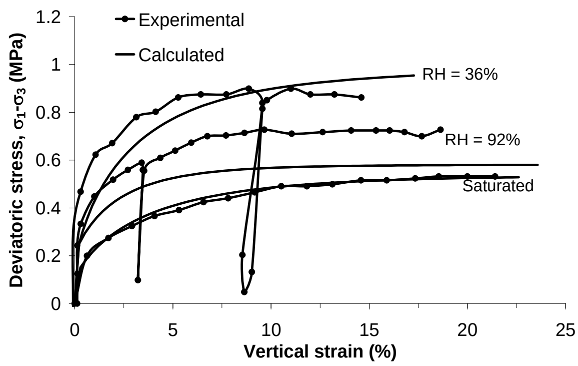

Figure 4: Triaxial tests at different relative humidity values and at 0.1 MPa confining stress (experimental results by Chávez, 2004)

3.1 Clay core

The clay core of the dam (w_L = 38%, PI = 18.5%) was also tested on samples compacted at Standard Proctor optimum. Oedometer tests results are plotted in Figures 5 and 6. The behaviour of the clay has been model using BBM (Alonso *et al.*, 1990) in order to calibrate the constitutive parameters.

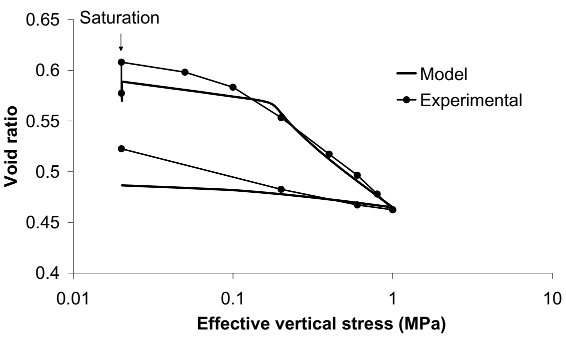

Figure 5: Saturated oedometric test on a compacted clay sample initially saturated at constant vertical stress (0.02 MPa).

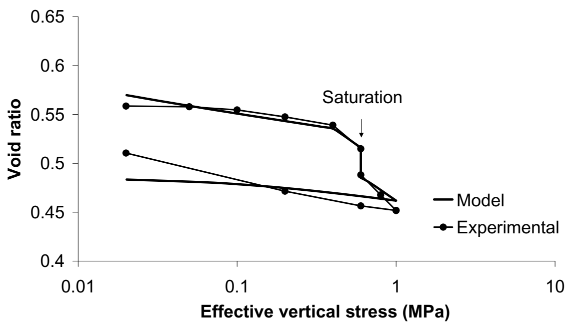

Figure 6: Oedometric test on a compacted clay sample a 1 MPa of suction. Saturation at constant vertical stress (0.6 MPa).

3.3 Foundation soils

The alluvium of the Pancrudo River was identified as a sequence of three horizontally layered strata: an upper layer of pervious sandy silt and gravels, 5 m thick, an intermediate soft clayey and silty stratum (deltaic deposits), 12 m thick, and a lower level of clayey sands and gravels 4 m thick directly over the shale substratum. In all levels thin sequences of impervious/pervious soils explain the fast consolidation of the entire alluvial stratum.

4. MODELLING DAM CONSTRUCTION

Once the models have been calibrated by back-analysis of laboratory tests, the hydro-mechanical response of the dam has been simulated. A finite element model of the dam using quadrilateral elements was built in a plane strain approximation of the central instrumented cross-section (Fig. 7).

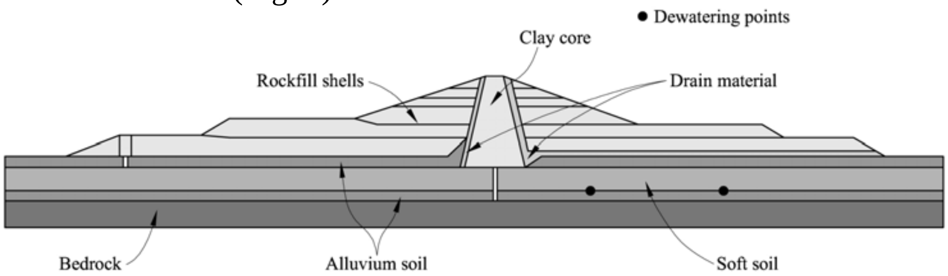

Figure 7: Model of central cross-section of Lechago dam for modelling.

The construction of the dam was simulated by successive soil layers incorporated at the appropriate time. Initial conditions introduced in the model are indicated in Table 3 and 4. The following stages are considered in the calculation:
Stage 1: Construction until elevation 874 in the period July to December of 2006.
Stage 2: Stop construction from January 1st to June 30th of 2007.
Stage 3: Construction until elevation 886 during July and August of 2007.
Stage 4: Preloading-ramp during September of 2007 and phreatic level lowering.
Stage 5: Preloading during October and November of 2007 and phreatic level lowering.
Stage 6: Unloading during December of 2007 and phreatic level lowering.
Stage 7: Construction until final elevation (895 m) during January and February of 2007.

4.1 Results of dam construction simulation

Calculated vertical displacements are compared with measurements in Figure 7. The magnitude of the measured values is in general well captured. Settlement records also react to the step-wise history of loading but in a more progressive manner than the total stresses due to consolidation effects in the foundation and the compacted structure.

Pore water pressures are calculated and compared with measurements in Figure 8. Consider first the piezometers located in the saturated foundation soil (Figs. 8a).

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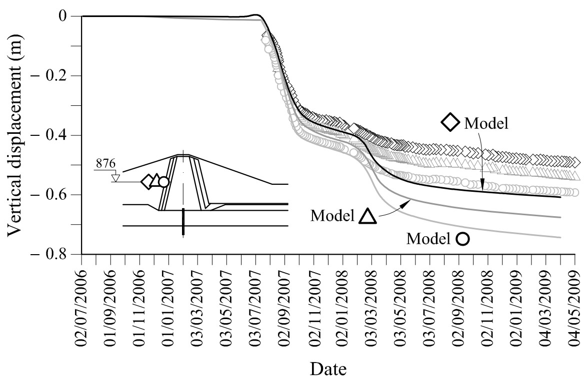

Figure 7: Comparison of measured and calculated differences of vertical displacements between the measurement gauge and the reference location.

The pumping tests, especially the third one (final months of 2007) is reflected in all measurements. The model also reacts in a similar way.

The response of the clay core is plotted in Figure 8b. Piezometers located in upper levels cannot record the prevailing suction. The model calculates suction values not shown in the figure because of the pressure scale of the graph reflects the water level elevation upstream (6 m) which took place in March 2009.

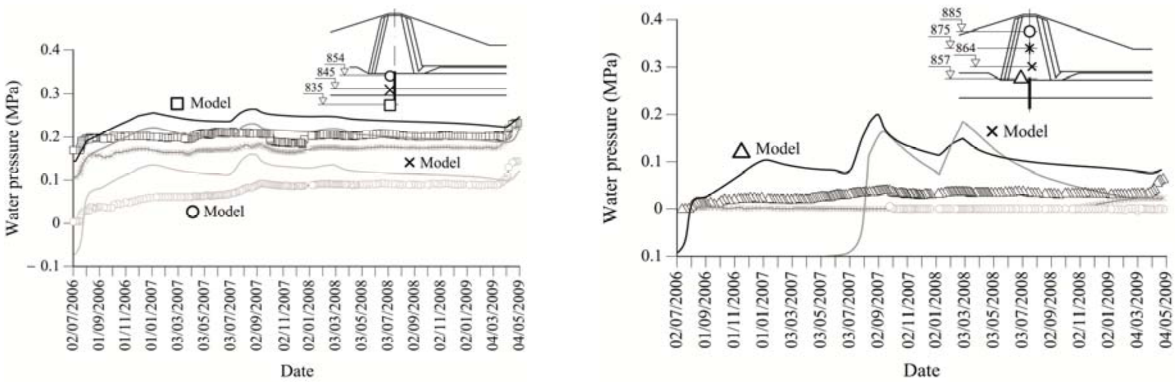

Figure 8: Comparison of measured and calculated pore water pressure. (a) Foundation soils, under the core; (b) clay core.

4. CONCLUSIONS

The construction of Lechago dam has been modelled. Several kinds of materials are involved in the dam: a soft saturated clay foundation limited by pervious granular layers, compacted quartzitic shale in the shells and a medium plasticity clay core.

Lechago dam presents an interesting feature for its analysis because an extensive previous experimental investigation of the rockfill shells is available. According to the results obtained in the laboratory test simulations, the constitutive models used, the Rockfill model by (Oldecop and Alonso, 2001) and the BBM by (Alonso *et al.* 1990) are able to reproduce satisfactorily the behaviour exhibited by the materials at different values of Relative Humidity and during saturation of the samples.

All the stages of the dam construction have been reproduced. A comparison of the measured and calculated vertical settlements and pore water pressure at different elevations of the dam has been given in the paper. Settlements include the deformation response of the foundation and the compacted materials. The recorded settlements are satisfactorily simulated. Lechago dam experienced large total vertical displacements up to 1 m in the central cross-section.

The predicted response of the dam under an assumed programme of impounding is given in Alonso et al. (2011). In the future, once impounding occurs, it will be possible to compare predictions with actual dam performance.

REFERENCES

Alonso, E.E., Olivella, S., Soriano, A. and Pinyol, N.M. (2011) Modelling the response of Lechago earth and rockfill dam. *Géotechnique*. Accepted.

Olivella, S., Gens, A., Carrera, J. and Alonso, E.E. (1996) Numerical formulation for simulator (CODE_BRIGHT) for coupled analysis of saline media. Engineering Computations 13 (7), 87-112.

Oldecop, L. and Alonso, E.E. (2001) A model for rockfill compressibility. *Géotechnique* 51 (2): 127-139 (2001).

Chávez, C. (2004) Estudio del comportamiento triaxial de materiales granulares de tamaño medio con énfasis en la influencia de la succión. *Doctoral Thesis*. UPC, Barcelona (2004).

Alonso, E.E., Gens, A. and Josa, A. (1990) A constitutive model for partially saturated soil. *Géotechnique* 40 (3), 405-430.